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# A neutral atom quantum register

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## Abstract

We demonstrate the use of a string of Caesium atoms trapped in our standing wave dipole trap [1] as a quantum register. We have initialized, selectively addressed, coherently manipulated, and state selectively detected the hyperfine states of individual atoms within the string using microwave radiation and resonant laser pulses [2].

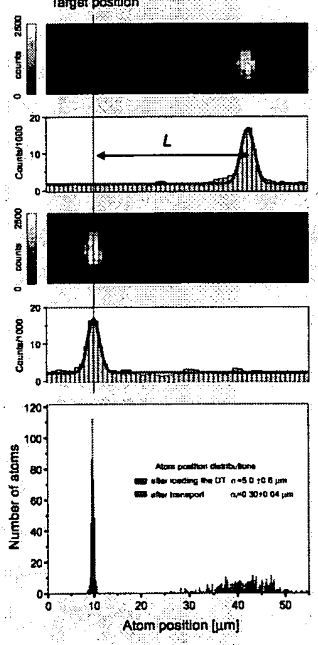
To spectroscopically distinguish atoms we apply a magnetic field gradient which produces a position-dependent Zeeman shift of the atomic transitions. Using a CCD camera we spatially resolve individual atoms within the trap [3], and get information about their exact positions [4]. The population of each individual atom can coherently be transferred by applying microwave radiation at the corresponding resonance frequency of the atom. The population of a neighbouring atom is not affected if its distance to the addressed atom is larger than 2 µm.

The coherence properties of the atoms are characterized by observing Rabi oscilations on single atoms which show no contrast decay within the measurement time of 200 µs. Using the standard spin-echo technique the irreversible dephasing time T2' was determined to be 600 µs.

The absolute position of a trapped atom can be determined with a precision of 130nm within 1.5 s. Furthermore, it is actively controlled by means of our optical conveyor belt, which allows us to transport the atom to a chosen position along the trap axis over a millimeter-scale distance [1, 5]. The accuracy of the position control is 300 nm and is limited by technical rather than fundamental reasons [4]. The absolute position control is an important prerequisite for e. g. introducing atoms into an optical resonator, which will enable controlled coherent interaction between two or more atoms.

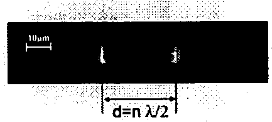
[1] D. Schrader *et al.*, Appl. Phys. B 73, 819 (2001)
[2] D. Schrader *et al.*, submitted to PRL
[3] Y. Miroshnychenko *et al.*, Optics Express 11, 3498 (2003)
[4] I. Dotsenko *et al.*, in preparation
[5] S. Kuhr *et al.*, Science 293, 278 (2001)

## Absolute position control

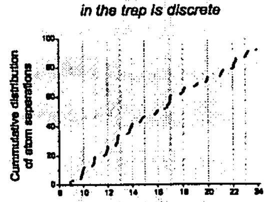



- load one atom into the dipole trap
- take first picture
- calculate distance $L$ to the target position
- transport atom over the distance $L$
- take second picture
- determine the final position of the atom

### Sub-diffraction mapping of the dipole trap

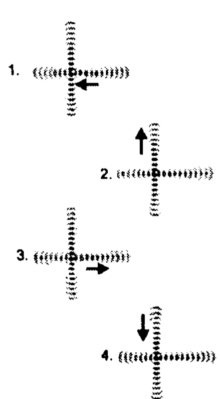



*distance between atoms in the trap is discrete*



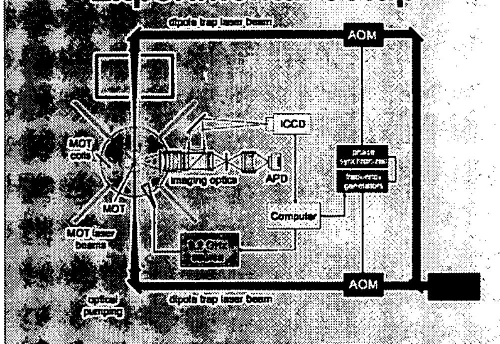

### Outlook

**Relative position control: sorting of atoms using a perpendicular DT**



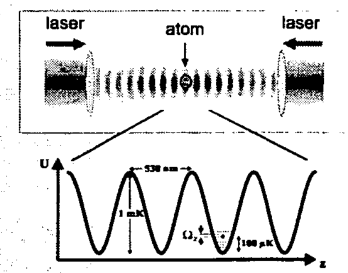

*sorting of atoms will allow us to couple arbitrary pairs of atoms out of the string*

## Experimental setup



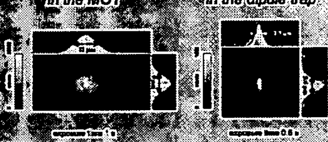

### Atom in the dipole trap

*AC Stark shift*



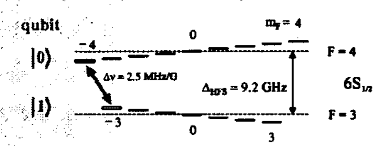

### Imaging a single atom

*In the MOT* *In the dipole trap*



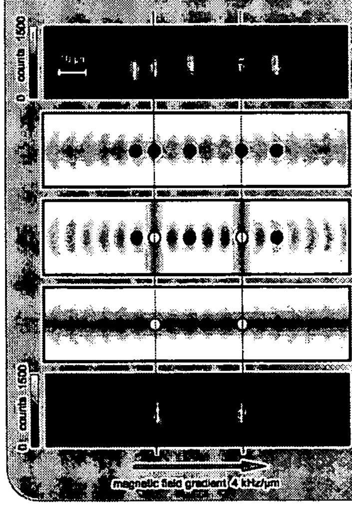
### Cesium ground state

*in the presence of a magnetic field*




## Addressing of individual qubits of the register

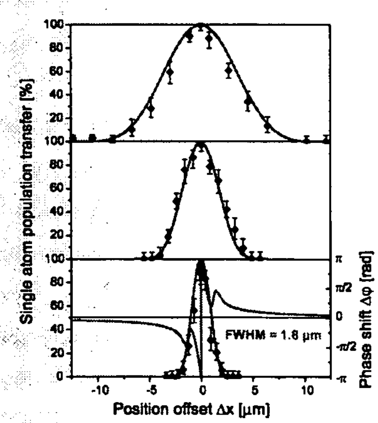
### Experimental sequence




- take first picture
- determine atom positions
- calculate resonance frequencies
- prepare atoms in |F = 4, $m_F$ = -4>
- apply microwave pulses
- apply push-out laser which removes atoms in F=4 from the trap
- take second picture

### Spatial resolution

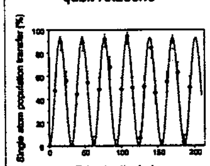
*experimental results and theoretical simulations*




## Quantum information in the register

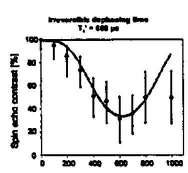
**Rabi oscillations on single atoms**

*qubit rotations*

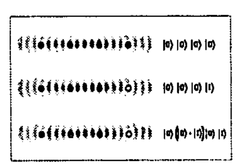



**Spin echo measurements**

*coherence time*



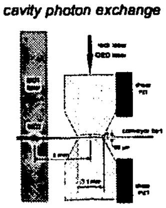

**Information stored in the quantum register**



## Outlook

**Placing atoms into a high-Q optical resonator**

*controlled interaction between atoms via cavity photon exchange*



Supported by the Deutsche Forschungsgemeinschaft and by the European Commission